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FLOW SEPARATION IN CONICAL DIFFUSORS

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ABSTRACT. Detailed study of the flow structure in the inlet section of a diffuser, where the transition from a cylindrical channel to a conical channel occurs. The effect of the aperture angle of the diffuser on the occurrence of flow separation is noted, as well as the existence of a considerable nonuniformity of the flow in the transverse direction. It is shown that the local positive pressure gradients in the diffuser in the presence of a corner bend or a section of great steepness at the inlet may be significantly greater and the actual velocity profile may be more deformed than the results of a calculation based on mean flow rates indicate.

Designation

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n — degree of diffuser expansion; α — diffuser opening angle;
 x, y — longitudinal and transverse coordinates; L, D — the length and diameter of the diffuser cross section; F — cross section area; c — flow rate;
 P — static pressure; P_d — static pressure at the bend; C_0 — arbitrary velocity, equivalent to isentropic heat transfer between the pressure of total braking in front of the diffuser P_0 and the static pressure behind it;

$n_{\text{eff}} = \frac{F_{2 \text{ eff}}}{F_1}$ — the effective expansion ratio; $\xi = \frac{P_2 - P_1}{\frac{\rho c_1^2}{2}}$ — the pressure reduction coefficient; ζ_n — total losses in the diffuser; $Re = \frac{D_1 c_1}{\nu}$ — Reynolds number; λ — dimensionless velocity.

*Numbers in the margin indicate pagination in the original foreign text.

Indices

1 - diffuser input cross section; 2 - diffuser output cross section;
s - separation cross section; w - flow parameters at the wall;
0 - parameters of total braking.

The theoretical calculation of losses and the selection of optimal diffuser geometric parameters depends essentially on the correct determination of the zone of non-separated flow. For this purpose, as a rule, various parameters of the boundary layer are used. The limiting values of these parameters are determined experimentally.

The numerical values of the limiting parameters fluctuate within wide limits. For example, the limiting value of the Bury parameter Γ_s changes from -0.028 to -0.12 according to various authors. The parameter $H = \delta^*/\delta^{**}$ used for determining the separation changes from 1.8 to 3, etc.

For flow in channels, the calculation of these parameters is complicated by the necessity of taking into account the reciprocal influence of the boundary layer on the velocity distribution over its outer boundary. In addition, an experimental study of plane and conical diffusers raises some doubt as to the possibility of determining the flow in them using methods employed in boundary layer theory.

One of the reasons for these doubts is the well-known fact that separation occurs in diffusers when a certain limiting angle of opening α_s is reached.

Based on the experimental data, the value of α_s is not a constant, but depends on several factors. According to data from [1] [2], the primary factor is the expansion ratio for the diffuser n . Based on data given in [2], this dependence (which is shown in Figure 1) shows that α_s sharply decreases with an increase in n , and strives to a certain constant value equal to $7 - 8^\circ$.

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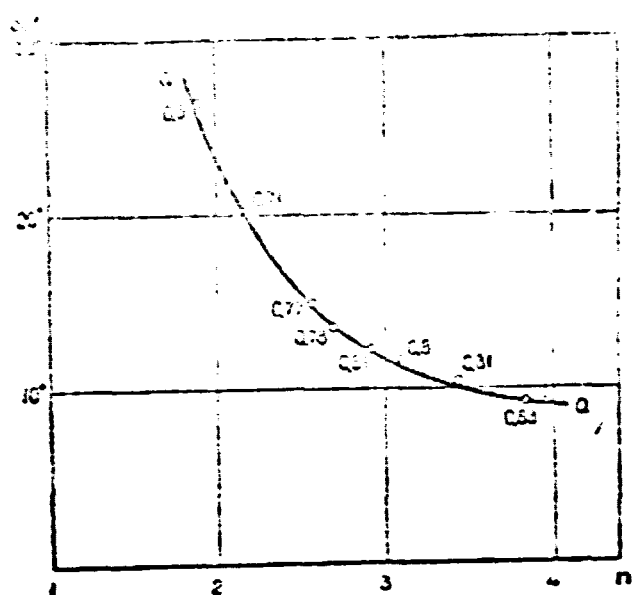


Figure 1. Line of limiting parameters of plane and conical diffusers without separation.

Since plane and conical diffusers are entirely determined by two dimensionless geometric parameters, the dependence $\alpha_s = f(n)$ essentially separates diffusers with non-separated flow (the zone lying above the curve in Figure 1) from diffusers with periodic and stationary separation.

The great influence of the diffuser angle of opening on the development of separation, and the apparent breaks between this

parameter and the customary criteria leads to the conclusion that a detailed study must be made of the flow structure in the diffuser input section. At this location, there is a change from a cylindrical channel to a conical channel. This change, both in plane and in conical, diffusers is accompanied by a sharp change in the steepness. The magnitude of this steepness in this zone strives to infinity when there is a corner bend. The region under consideration is a region of pole-like singular points, whose existence in the flow leads to significant disturbance of the flow. This disturbance consists of the fact that, in the region with great steepness, there are increased, longitudinal, negative (in front of the diffuser input) and positive (at the input section of the diffuser itself) pressure gradients. This phenomenon is well known [3], and Figure 2 shows graphs based on our experimental data. When the angle α increases, the flow acceleration increases in the nozzle, and the positive gradients in the channel diffuser section increase also. /100

Experiments have also shown that the corner bends and the section of great steepness lead to very uneven flow in the transverse direction. Figure 3 shows the static pressure distribution for three different channel cross sections.

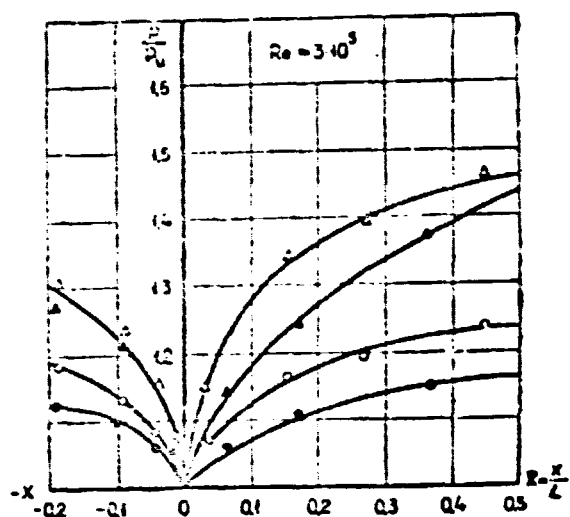


Figure 2. Distribution of static pressure over the input section of a conical diffuser.

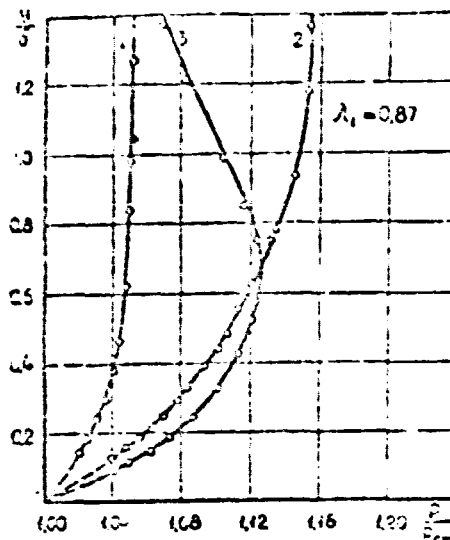


Figure 3. Distribution of static pressure in transverse cross sections of plane diffuser with angle of opening $\alpha = 10^\circ$

1 - in cross section 4 mm from the corner bend; 2 - above the bend; 3 - at a distance of 4 mm from the bend in the diffuser section of the channel.

The greatest nonuniformity is observed over the corner bend. The change in the static pressure in this section amounts to 15%, as compared with the pressure on the wall. In the section behind the corner (in the channel section which can be expanded) the pressure first suddenly increases, and then begins to decrease. Consequently, in the diffuser region close to the wall, where the liquid has minimum kinetic energy, there is a sharp, local braking of the flow, and the degree of this braking at the velocity λ_1 is determined by the diffuser angle of opening α . In the case of equal velocity distribution over the diffuser axis, large input disturbances correspond to large angles α .

Thus, local, positive pressure gradients in the diffuser may be much larger when there is a corner bend or a region of great steepness at the input. The actual velocity profile is more deformed than would follow from calculating the flow in terms of the average flow velocities.

It is not valid to compare the experimental data obtained in diffusers with a corner bend with the calculated boundary layer characteristics, even

if the actual velocity distribution over the channel axis lies at the basis of the calculation. This is because boundary theory does not take into account fluid flow conditions near singular points. In this connection, one of the possible reasons for the large scatter in the values of flow separation criteria, found from the results of diffuser tests, is that the calculations did not take into account additional deformation of the velocity profile at the diffuser input section under the action of local, increased pressure gradients, whose magnitude is determined by the input conditions.

Let us compare the experimental data in Figure 1, obtained in diffusers with a corner bend [1], [2], with the results derived from tests of diffusers with a smooth transition from the nozzle section to the diffuser section.

Let us select the effective diffuser expansion ratio with respect to this cross section as the characteristic of the cross section in which separation occurs. In the general case, it is determined by the expression:

$$n_{\text{eff}} = \frac{F_{2 \text{ eff}}}{F_1}$$

where $F_{2 \text{ eff}} = F_2 - F^*$; F^* is the area of displacement.

The effective expansion ratio unequivocally determines the degree of pressure increase in the diffuser in the case of incompressible liquid flow. Actually, by definition, the pressure recovery coefficient of the diffuser ξ shows what portion of the kinetic energy at the diffuser input is transformed into potential pressure energy.

Knowing ξ , we can readily find the total losses ζ_n :

$$\zeta_n = 1 - \xi.$$

On the other hand, it can be shown that the coefficient of total losses ζ_n is expressed by the average velocity at the diffuser input c_1 and the relative velocity c_0 corresponding to the temperature drop between the pressure P_0 at the input and the pressure at the output P_2

$$\zeta_n = \frac{c_0^2}{c_1^2}.$$

When there is a potential core in the flow, the velocity c_0 is equalized by the maximum velocity $c_{2 \max}$ at the diffuser output. From the equation of discontinuity, we have

$$\zeta_n = \frac{c_0^2}{c_1^2} = \frac{1}{n_{\text{eff}}^2}.$$

Consequently,

$$n_{\text{eff}} = \frac{1}{\sqrt{\zeta_n}} = \frac{1}{\sqrt{1-\xi}}.$$

Thus, the quantity n_{eff} is the most important energy characteristic of the diffuser.

The numbers on the curve in Figure 1 correspond to the experimental values of the pressure recovery coefficients, which characterize the maximum possible efficiency of diffusers with the given angle of opening. Consequently, the limiting value of the effective expansion ratio n_{eff} in the given range of angles α changes very greatly; from $n_{\text{eff}} \approx 2.3$ for $\alpha = 7 - 8^\circ$ to $n_{\text{eff}} \approx 1.4$ for $\alpha = 20^\circ$.

If the conversion from the nozzle section of the channel to the diffuser section is smooth, the scatter of the limiting effective expansion ratio as a function of the angle of opening is greatly reduced.

Figure 4 gives the results of tests on conical diffusers with angles of opening $\alpha = 10, 15$ and 20° and expansion ratios of $n = 3$ and $n = 4$. The

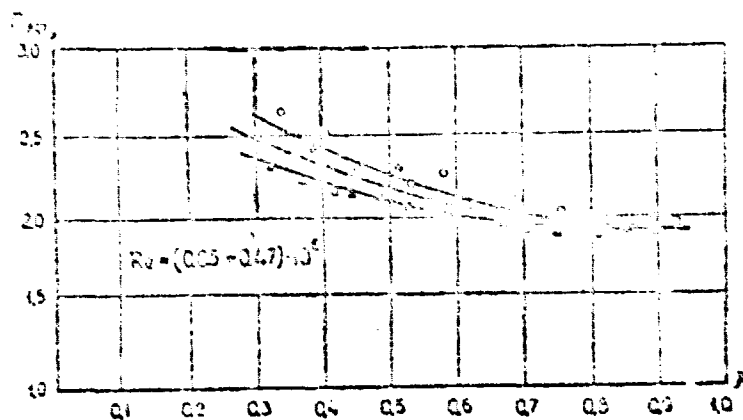


Figure 4. Limiting values of the effective expansion ratio of conical diffusers for different velocities λ_1 .

established by determining the velocity profiles with total head probes. The Re number, calculated from the flow input parameters and the input section diameter, changes from $0.05 \cdot 10^6$ to $0.47 \cdot 10^6$.

An examination of Figure 4 reveals that in diffusers with a rounded input the influence of the angle α on $n_{eff\ s}$ decreases considerably. In spite of the small difference in the values of $n_{eff\ s}$ for the angles $\alpha = 20$ and 10° , flow separation in diffusers with a large aperture angle begins at small values of $n_{eff\ s}$. It is plausible that a smoother transition with a larger coupling radius could eliminate this difference in general.

There is also an increase in the absolute limiting effective expansion ratio for small velocities λ_1 , as compared with the experimental values given in Figure 1 for an incompressible fluid, obtained in diffusers with a corner bend. It is apparent that this is due to a decrease in the input disturbances, as a result of which flow separation begins later.

In spite of the great change in Re, no influence upon the limiting effective expansion ratio could be detected. A similar result from an experimental study of the separation point location is given in [4]. In this study, it is shown that the effective expansion ratio equals two in the case of

coupling radius of the nozzle and diffuser section is $r_1 = 2\text{mm}$. Experiments were carried out on a steam-driven aerodynamic profile, assuming an independent change in the initial flow parameters. The M_1 and Re numbers were used as the parameters. By the appropriate selection of these parameters, a pre-separation state of the flow was reached in the diffuser output sections. This state was

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incompressible liquid flow.

It must be pointed out that we are discussing the maximum possible value of n_{eff} , and not the separation point position. Full separation occurs at the section where the effective expansion ratio reaches its limiting value for the given velocity λ_1 .

Thus, in the first approximation a unique dependence $n_{\text{eff } s} = f(\lambda_1)$ may be assumed for angles α up to approximately 20° .

It is advantageous to use $n_{\text{eff } s}$ as the unique criterion for flow separation in diffusors. It has a certain advantage compared with other well-known criteria. For example, in the calculation of the separation location with subsequent approximations, when the velocity changes along the channel axis, it is sufficient to find the values of the thickness δ^* , which somewhat simplifies the computations. In addition, as experiments have shown, /103 the quantity n_{eff} changes very little in the output section. When designing an optimum diffusor, the effective expansion ratio in the output section may be assigned somewhat smaller values of $n_{\text{eff } s}$ for a given velocity λ_1 . This reduces somewhat the diffusor length without greatly lowering its efficiency.

However, the basic advantage of $n_{\text{eff } s}$ as the separation criterion lies in the fact that the dependence shown in Figure 4 makes it possible to take into account the influence of compressibility on the separation point position.

A decrease in $n_{\text{eff } s}$ with an increase in λ_1 may be explained as follows in physical terms. Experiments have shown that an increase in the velocity λ_1 leads to further increase of the longitudinal pressure gradients and an increase in the flow non-uniformity in the transverse section in the diffusor entrance region, i.e., an increase in the velocity is similar to an increase in the diffusor angle of opening α . In addition, as larger subsonic and transonic velocities λ_1 are approached, changes in the flow become predominant due to its compressibility, and the influence of the angle α changes secondarily.

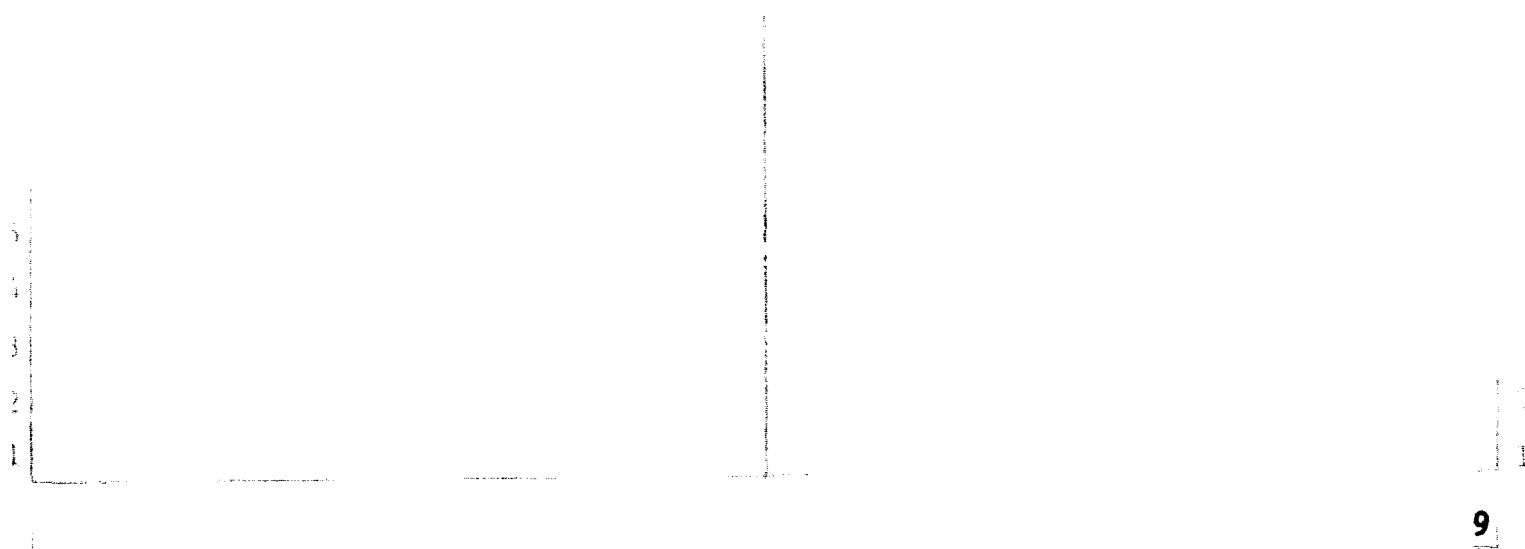
In conclusion, we should note that the effective expansion ratio examined here is determined from the arbitrary area of displacement F^* calculated with respect to the arbitrary velocity c_0 , and only in the presence of a potential core, when the pressure of the total braking P_{01} in front of the diffuser coincides with the maximum pressure P_{02} behind it. It is identical with the customary effective expansion ratio calculated with respect to the maximum velocity in the output section. The following conclusions may be drawn.

The participation of the diffuser angle of opening α in the development of separation is determined by disturbances introduced into the flow by the corner bend or the great steepness at the diffuser input.

The formation of flow separation in diffusers may be characterized by the limiting effective expansion ratio of the diffuser, which may be advantageously used as the separation criterion.

The effective expansion ratio in the separation section does not depend on the Re criterion. However, the geometric section, where n_{eff} reaches its limiting value, is determined by the Re number.

The increase in λ_1 contributes to an increase in the positive input pressure gradients, which leads to earlier flow separation, other conditions being equal. As a result, when the flow velocity increases at the diffuser input, the limiting effective expansion ratio decreases.



REFERENCES

1. Kline, S. I., D. E. Abbot and R. W. Fox. Optimum Design of Straight Walled Diffusers. Trans. ASME. ser. D., Vol. LXXXI, No. 3, 1959.
2. Kline, S. I. Of the Nature of Stoll. Trans. ASME ser. D., Vol. LXXXI, No. 3, 1959.
3. Litti, R. H. and S. W. Wilbur. Performance and Boundary Layer Data from 12° and 23° Conical Diffusers of Area Ratio 2.0 at Mach Numbers up to $7.5 \cdot 10^6$. NACA Rep. 1201, 1954.
4. Seymour Lieblets. Loss and Stoll Analysis of Compressor Cascades. Trans. ASME, ser. D, No. 31, 1959, No. 3.

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